Limited Tillage and Energy Use with Furrow-Irrigated Grain Sorghum

R. R. Allen, J. T. Musick, D. A. Dusek
MEMBER ASAE MEMBER ASAE

ABSTRACT

LIMITED tillage was successful for managing continuous grain sorghum with furrow irrigation in the Southern High Plains. Grain yields were generally proportional to seasonal water use. The limited tillage treatment, mulch-subsoiling, increased irrigation water intake by 10 percent and grain yield by 8 percent as compared with clean tillage and chiseling. Another limited tillage treatment, bed-splitting, resulted in yields equal to those for the clean tilled treatment yet cost \$14.50/ha less because of lower fuel and labor requirements. Time and fuel energy requirements for limited tillage were only about half those for clean tillage. Mulch-subsoiling netted \$40/ha more than clean tillage because of the greater yield and lower production cost.

INTRODUCTION

In the Southern High Plains, about 0.7 million ha of irrigated grain sorghum are grown, much of which is furrow irrigated. Limited rainfall, decreasing groundwater for irrigation, and limited supplies of increasingly more expensive energy emphasize a need for a more efficient crop-production method. In a 2-yr study of no-till, furrow-irrigated grain sorghum (Allen et al., 1975), problems of the no-till system were (1) inadequate control of volunteer plants before seeding; (2) some difficulty of seeding into undisturbed soil; and (3) partial blocking of existing irrigation furrows by bunching of residues. We conducted this study to evaluate limited tillage systems which might overcome the limitations of no-till by (a) encouraging volunteer plants to germinate before seeding and (b) controlling volunteer crop seedings with shallow tillage of existing bed-furrows (sweep-rod weeder), which would also reopen water furrows.

PROCEDURE

The study was established on existing bed-furrows after harvesting the 1974 grain sorghum crop. The soil, a fine-textured, slowly permeable Pullman (Torrertic Paleustoll) clay loam occupies about 1.2 million ha of irrigated land in the Southern High Plains and was described by Taylor et al. (1963). The experiment had a randomized design of four tillage treatments as main plots and two irrigation levels as subplots. Plots were twelve 1-m spaced bed-furrows wide by 210 m long on a 0.8 percent slope. Since tillage method and related management of crop residue affect soil water storage, two irrigation levels, adequate (I-A) and limited (I-L), were used to evaluate crop response with varying soil water content. The adequate and limited irrigation levels averaged five and three applications, respectively.

TABLE 1. TILLAGE SEQUENCES USED IN FOUR TREATMENTS AT BUSHLAND, TEXAS

Treatment	Operation: Fall	Operation: Spring
	Clean tillage (residue incorporated)	
T-1 (Disk-chisel)	Disk Chisel 20 cm deep	Disk Chisel NH_3 15 cm deep Bed Sweep-rod weed Plant
T-2 (Disk)	Disk-winter to early spring	Disk Chisel NH_3 15 cm deep Bed Sweep-rod weed Plant
	Limited tillage	
T-3 (Bed-split)	Shred stalks Bed-split with lister	Furrow chisel NH_3 15 cm deep Rolling cultivate Plant
T-4 (Mulch-subsoil)	Furrow subsoil NH_3 20 cm deep	Sweep-rod weed Plant

Four tillage treatments provided a range in tillage intensity and residue management. Primary tillage treatments were conventional disking and chiseling (T-1), disking only (T-2), bed-splitting (T-3), and mulch-subsoiling of existing furrows for combined soil loosening and anhydrous ammonia (NH_3) application (T-4). The mulch-subsoiler had sweep-type wings attached 10 cm above the points, which completely undercut the old furrows. The tillage sequences are shown in Table 1.

Anhydrous ammonia was applied to all treatments at 150 kg N/ha. Sorghum was seeded in two rows (25-cm apart) on 1-m spaced beds because previous research (Allen et al., 1969) showed 15 percent higher grain sorghum yields with double rows than with single rows on 1-m spaced beds. Exploratory research in 1974 showed that unit planters, placed side by side (25-cm spacing) for double-row seeding, did not operate properly when seeding into grain sorghum residue. The single disk grain drill was successfully operated in residues and was used in this study. The grain drill had 16 openers spaced 25 cm apart (Fig. 1) with the two seed spouts operating in the furrows being covered. The disk openers were positioned so the concave side of the disk faced toward the bed, which helped to maintain bed shape. The wheel spacing on the grain drill was about 4 m, which fit in every fourth furrow.

Article was submitted for publication in January 1979; reviewed and approved for publication by the Soil and Water Division of ASAE in April 1979.

Contribution from Agricultural Research, Science and Education Administration, USDA, in cooperation with The Texas Agricultural Experiment Station, Texas A&M University.

The authors are: R. R. ALLEN, J. T. MUSICK, Agricultural Engineers and D. A. DUSEK, Agricultural Research Technician, USDA-SEA-AR; USDA Southwestern Great Plains Research Center, Bushland, TX.

This article is reprinted from the TRANSACTIONS of the ASAE (Vol. 23, No. 2, pp. 346, 347, 348, 349, 350, 1980)
Published by the American Society of Agricultural Engineers, St. Joseph, Michigan

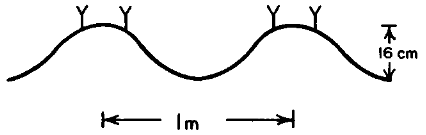


FIG. 1 Bed-furrow configuration showing location of 25-cm spaced grain sorghum rows on top of the beds.

A medium, late-maturity sorghum hybrid was seeded in 1975 and 1976 at 10 kg/ha. In 1975, plots were preplant-irrigated on May 22 and sorghum was planted on June 4. Rainfall before seedling emergence caused surface crusting and replanting was required on June 17. In 1976, the sorghum was planted on May 12 and irrigated for emergence on May 18. Atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-**s**-triazine] was applied (postemergence) at 2 kg/ha active ingredient for weed control.

Irrigation water inflow rates were measured with a propeller meter and adjusted to individual furrows through gated pipe (Allen and Musick, 1972). Individually calibrated portable "H" flumes equipped with water level recorders were used to measure furrow runoff. Gravimetric soil samples were taken by 30-cm increments to 180 cm at beginning and end of growing season for soil water content determination. Seasonal water use was determined from net soil water depletion between planting and harvest, plus irrigation intake and seasonal rainfall. In 1975, greenbug (*Schizaphis graminium*) infestations required chemical spray treatment of 9.55 kg/ha malathion (diethyl mercaptosuccinate **s**-ester with **o**, **o** dimethyl phosphoro-dithioate) for control on July 30. In 1976, the same hybrid with inbred greenbug resistance was used so greenbugs, though present, did not require chemical control. Sorghum was harvested on October 22, 1975 and October 25, 1976. Samples for grain yield were harvested from three (2-m by 25-m) areas from each plot with a self-propelled plot thresher.

RESULTS AND DISCUSSION

Tillage and Seedbed Preparation

The clean tillage operations (T-1 and T-2), which are common practice, were accomplished without any unusual difficulty. With limited tillage, the bed-splitting operation (T-3) exposed root clumps from the previous crop and left the surface rough (Fig. 2). This condition was corrected in the spring with a rolling cultivator, which smoothed the seedbed and controlled volunteer sorghum and weeds. On the mulch-subsoiling (T-4) treatment, the fall subsoil application of NH_3 in the furrow (Fig. 3) loosened the soil enough for the sweep-rod weeder (Fig. 4) to penetrate and properly perform late spring cultivation for volunteer sorghum and weed control.

FIG. 2 Bed splitting exposed root clumps and left a rough surface which was later smoothed with a rolling cultivator.

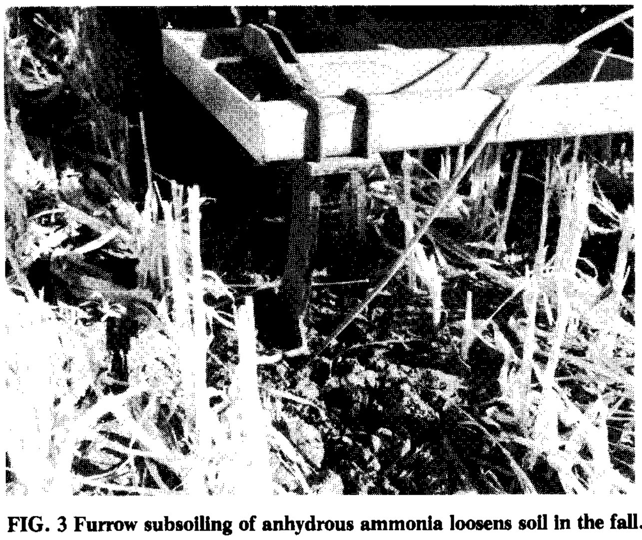
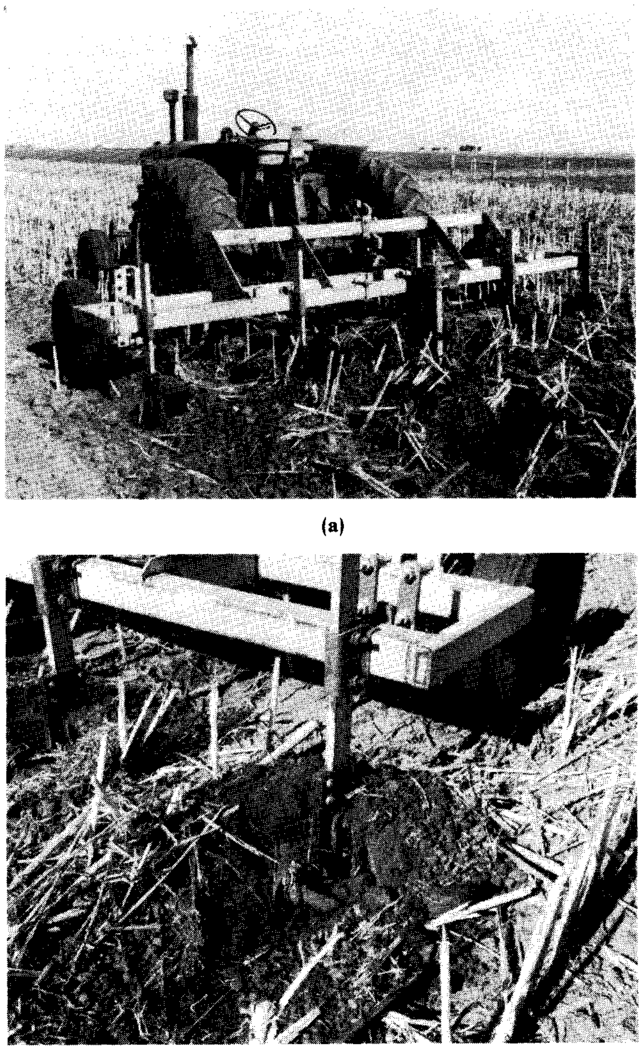


FIG. 3 Furrow subsoiling of anhydrous ammonia loosens soil in the fall.



(a)

(b)

FIG. 4 (a) Sweep-rod weeder performing spring cultivation for controlling weeds and volunteer plants on sorghum residue plot. (b) PTO-driven counter rotating rod undercuts existing bed, while sweep-shovel arrangement reopens furrow.

FIG. 5 Grain drill seeding two 25-cm spaced rows through crop residue on 1-m spaced beds. Stalks occasionally clogged the drill and required clearing by operator. Seed spout opener on left is closed.

Seeding, Stand Establishment, and Growth

Seeding with the grain drill was satisfactory on T-1, T-2, and T-3 plots. Stalks occasionally clogged the drill on the T-4 residue plots (Fig. 5), which required the operator to closely observe and intermittently stop to clear the seeder. Plant stands were generally satisfactory on all treatments though there were a few skips when the seeder plugged on T-4 plots. In 1976, when the crop was dry-seeded and irrigated for emergence, some volunteer sorghum emerged with the new seedlings on T-4 plots.

Plants were headed by August 25, 1975, and August 15, 1976. Plant heights with limited (I-L) irrigation averaged about 15 cm shorter than with adequate irrigation (I-A). With adequate irrigation, plant heights for treatments T-1 through T-4 averaged 1.20, 1.15, 1.20, and 1.25 m, respectively. With limited irrigation, T-2 had severe plant-moisture stress in the late season.

Yields

Grain yield data are presented in Table 2. Yields ranged from 4200 to 6600 kg/ha in 1975 and from 4300 to 7200 kg/ha in 1976. Yield potential was lower in 1975 because of the late reseeding date. All treatments responded to adequate irrigation. With adequate irrigation, the 2-yr average yields with T-1 and T-3 treatments were about equal. With limited irrigation, yields with T-1 and T-3 were not significantly different. The yield response to chiseling on clean-tilled plots (T-1) was 430 kg/ha with adequate irrigation and 900 kg/ha with limited irrigation. The T-4 mulch-subsoiling plots had the highest yields under both irrigation levels. The higher T-4 yields resulted from more irrigation water intake and less evaporation loss because of the residue on the soil surface. Average yields for the T-4 treatment with limited irrigation equaled that of T-2 with adequate irrigation (5920 kg/ha), because seasonal water use (63.2 cm) was also equal for both treatments.

Irrigation and Water Use

When furrow irrigating the slowly permeable Pullman clay loam, intake usually averages 8 to 10 cm per application and wets the soil to about 60 cm deep. Grain sorghum on Pullman soil can deplete soil water to the 90-to 120-cm depth. If irrigation intake and depth of wetting are increased, yields may increase or the number

TABLE 2. GRAIN YIELD, SEASONAL RAINFALL, IRRIGATION WATER INTAKE, SEASONAL SOIL PROFILE DEPLETION, SEASONAL WATER USE, AND WATER-USE EFFICIENCY (1975-76)

Treatment		Grain yield	Seasonal rainfall	Irrigation intake: Per irrig.	Irrigation intake: Seasonal total	Seasonal soil profile depletion	Seasonal water use	Seasonal water use eff.
		kg/ha	cm	cm	cm	cm	cm	kg/m^3
1975								
I-A	T-1	5940 bc*	16.1	6.9	34.5 b*	-12.8†	63.4 ab*	0.940 a*
	T-2	5440 cd		7.1	35.4 b	-11.0	62.5 ab	0.860 a
	T-3	6160 ab		7.0	34.9 b	-14.3	65.2 ab	0.940 a
	T-4	6560 a		8.3	41.3 a	-14.2	71.6 a	0.920 a
I-L	T-1	4850 d	16.1	9.5	28.6 c	-11.7	56.3 c	0.860 a
	T-2	4190 e		9.5	28.4 c	-11.1	55.6 c	0.750 b
	T-3	5880 d		9.6	28.8 c	-14.1	59.0 bc	0.860 a
	T-4	5690 bc		11.5	34.5 b	-13.5	64.0 ab	0.890 a
1976								
I-A	T-1	6750 ab	22.8	8.8	52.9 a	+ 4.3	71.4 ab	0.950 ab
	T-2	6400 ab		7.3	43.7 b	+ 2.6	63.9 b	1.000 ab
	T-3	6650 ab		7.3	43.8 b	- 1.4	65.2 b	1.020 a
	T-4	7170 a		9.2	55.2 a	+ 3.7	74.3 a	0.970 ab
I-L	T-1	5460 c	22.8	10.2	40.8 b	+ 2.1	61.5 b	0.890 abc
	T-2	4340 d		9.0	35.8 c	+ 1.5	57.0 c	0.760 c
	T-3	4790 cd		9.1	36.5 c	+ 4.0	55.3 c	0.870 bc
	T-4	6160 b		10.7 b	42.7 b	+ 2.8	62.7 b	0.980 ab
Average								
I-A	T-1	6350 ab	19.4	7.9	43.7 ab	- 8.5	67.4 ab	0.945 ab
	T-2	5920 b		7.2	39.6 b	- 8.4	63.2 b	0.930 ab
	T-3	6400 ab		7.2	39.4 b	-12.9	65.2 b	0.980 a
	T-4	6860 a		8.8	48.3 a	-10.5	72.9 a	0.945 ab
I-L	T-1	5160 c	19.4	9.9	34.7 c	- 9.6	58.9 c	0.875 b
	T-2	4260 d		9.2	32.1 c	- 9.6	56.9 c	0.755 c
	T-3	4940 c		9.3	32.7 c	-10.1	57.1 c	0.865 b
	T-4	5920 b		11.0	38.6 b	-10.7	63.3 b	0.935 ab

*Column values for individual years followed by the same letter are not significantly different at the 5 percent level, according to Duncan's multiple range test.

†Negative and positive values show decreases and increases, respectively, during the growing season.

TABLE 3. AVERAGE TIME, DIESEL FUEL CONSUMPTION RATES, AND FUEL AND LABOR COSTS TO TILL AND PLANT FURROW-IRRIGATED CONTINUOUS GRAIN SORGHUM GROWN ON FINE-TEXTURED SOIL IN SOUTHERN HIGH PLAINS USING A 56-kW (75-HP) TRACTOR WITH 4-ROW EQUIPMENT

	T-1		T-2		T-3		T-4	
Operation	Time	Fuel	Time	Fuel	Time	Fuel	Time	Fuel
	h/ha	L/ha	h/ha	L/ha	h/ha	L/ha	h/ha	L/ha
Disk x (2)	1.2	21.0	1.2	21.0				
Chisel	0.6	11.7						
Disk	0.6	9.3	0.6	9.3				
Shred					0.6	9.3		
Bed-split					0.5	6.5		
Rolling cultivator					0.4	5.1		
Mulch-subsoil							0.6	12.0
Chisel NH_3	0.6	7.5	0.6	7.5	0.6	7.5		
Bed	0.5	7.5	0.5	7.5				
Sweep rod-weed	0.6	7.8	0.6	7.8			0.6	7.8
Plant	0.6	3.6	0.6	3.6	0.6	3.6	0.6	3.6
Spray atrazine	0.3	1.8	0.3	1.8	0.3	1.8	0.3	1.8
Total	5.0	70.2	4.4	58.5	3.0	33.8	2.1	25.2
			Labor and fuel costs					
	$/ha		$/ha		$/ha		$/ha	
Labor*	25.00		22.00		15.00		10.50	
Fuel†	8.50		7.00		4.00		3.00	
Total	33.50		29.00		19.00		13.50	

*Labor = $5/h
†Fuel = $0.12/L

of irrigations for a selected yield level may be reduced. Irrigation intake can be increased by chiseling and subsoiling or by effect of surface residue remaining after limited tillage.

Irrigation water intake, seasonal soil water depletion, seasonal water use, and the seasonal water-use efficiency are shown in Table 2. The residue in T-4 furrows slowed water advance, increased intake 10 to 20 percent, and resulted in more uniform wetting across beds and down the length of furrow run. The subsoiling on the T-4 plots was 5 cm deeper than the depth of chiseling on T-1 and T-3 plots, which could have caused some of the increased irrigation intake. Limited irrigation on T-4 plots averaged nearly as much intake (38.6 cm) as did adequate irrigation on T-2 and T-3 plots (38.5 cm average). Soil water intake for individual irrigation applications were larger with limited irrigation because of more soil profile drying and cracking. We experienced no problems in irrigating the limited tillage or clean tillage furrows.

In 1975, the soil was relatively moist when the T-1 plots were chiseled. Therefore, soil shattering was limited and irrigation intake was not affected. In 1976, when the soil was drier, chiseling increased intake from 35.8 to 40.8 cm with limited irrigation and from 43.7 to 52.9 cm with adequate irrigation.

Grain yields were generally proportional to seasonal water use. With adequate irrigation, differences in water-use efficiency related to tillage were not significant. With limited irrigation, water-use efficiency was significantly lower for the T-2 treatment.

Time-Energy Efficiency Costs

The four tillage treatments can be compared on the basis of time for operations, fuel consumption rates, and labor and fuel costs. Table 3 shows the time requirements and fuel consumption rates of four-row equipment and a 56-kW (75-hp) tractor for all operations through tillage, planting, and postemergence herbicide application. The fuel consumption values for atrazine spraying include the equivalent energy used to produce the herbicide.

Differences in fuel consumption between the treatments varied proportionately with the time required. The time requirement for T-1 (5.0 h/ha) was 2.4 times greater than that for T-4 (2.1 h/ha), whereas the fuel requirement for T-1 (70 L/ha) was 2.8 times greater than that for T-4 (25 L/ha). Table 3 also shows the costs of fuel and labor. Other costs were uniform for all treatments and are not included. The variable costs for clean tillage treatments were about double those of limited tillage. Net returns averaged $40/ha higher for the T-4 than for the T-1 treatment. This resulted from $20/ha lower costs and $20/ha more gross return with the higher yielding T-4 treatment, based on a $0.088/kg ($4/cwt) grain sorghum price.

Table 4 illustrates the complete fuel energy requirements of the sorghum tillage systems compared in this study. This includes the equivalent energy for producing and applying fertilizer, irrigation pumping, harvesting, and transporting grain to local market. Energy requirements for two dryland grain sorghum

TABLE 4. FUEL ENERGY EQUIVALENTS FOR SURFACE IRRIGATED (ADEQUATE WATER LEVEL) AND DRYLAND GRAIN SORGHUM SYSTEMS WITH VARYING TILLAGE AT BUSHLAND, TEXAS

	Irrigated				Dryland	
Operation	T-1	T-2	T-3	T-4	Wheat sorghum fallow	Continuous sorghum
	Diesel fuel equivalent, L/ha					
Till and seed	68.4	56.7	32.0	23.4	41.0	28.0
Fertilizer*	196.0	196.0	196.0	196.0		
Herbicide†	10.3	10.3	10.3	10.3	4.7	4.7
Irrigation‡	516.0	470.0	470.0	570.0		
Harvest	11.2	11.2	11.2	11.2	7.0	6.5
Transport§	7.5	7.5	7.5	7.5	1.9	1.4
Total	808.9	751.9	762.9	813.3	54.6	40.6

*170 kg/ha N as NH_3, 1.17 L diesel fuel/kg N equivalent for NH_3 (Miles, 1975)
†Diesel equivalent energy to produce and apply atrazine = 4.74 L diesel /kg A. I. (Jones, 1974)
‡76-m pump lift, 75 percent pump efficiency, 95 percent gear head efficiency.
§6,300 kg load, 16-km round trip to market.

systems are included for comparing with the irrigated systems. Total energy use for adequately irrigated sorghum production is about 16 times greater than that for dryland sorghum production, while only four times more grain is produced (Allen and Fryrear, 1977). Thus, irrigated sorghum production is only about 25 percent as energy efficient as dryland sorghum production. About 20 and 65 percent of the energy in irrigated production is used for producing and applying fertilizer and for pumping water, respectively. With deep well irrigation in the Southern High Plains, tillage may account for only 3 to 10 percent of the total energy used in grain sorghum production.

SUMMARY AND CONCLUSIONS

Continuous grain sorghum was successfully managed with furrow irrigation and limited tillage in the Southern High Plains. Sorghum grown with clean tillage was used for comparison. The limited tillage treatment, mulch-subsoiling (furrow-applied NH_3 and a preplant sweep-rod weeder cultivation of existing bed-furrows), increased irrigation water intake and grain yield. This treatment left previous crop residue on the soil surface, which contributed to the increases intake and yield, but caused some clogging of the planter. A possible solution to clogging by residue would be to plant single rows on 0.75-m spaced beds, rather than two rows on the wider 1-m spaced beds. The mulch-subsoiling treatment averaged $40/ha higher net return than did the clean tillage treatment of multiple disking and chiseling. Another limited tillage treatment, bed-splitting, had yields equal to disk and chisel (6350 kg/ha), yet cost $14.50/ha less because of lower fuel and labor requirements.

With clean tillage, chiseling plus disking increased average yield about 8 percent, the result of more irrigation water intake. Grain yields were generally proportional to seasonal water use. Seasonal water-use efficiency (production per unit of water used) was higher under adequate than under limited irrigation. The clean tillage treatment (disking without chiseling) had the lowest water-use efficiency under both limited and adequate irrigation.

Time and fuel requirements for limited tillage were only about half those for clean tillage. Of the total energy used to produce irrigated grain sorghum, about 65 percent is used for pumping water from wells, 20 percent to manufacture and apply fertilizer, and only 3 to 10 percent for tillage. Even though the tillage portion of the total energy use is relatively small, limited tillage can still be worthwile because it saves 40 to 50 L/ha of diesel fuel and decreases related production expenses and time.

References

1 Allen, R. R. and D. W. Fryrear. 1977. Limited tillage saves soil, water, and energy. ASAE Paper No. 77-2029, ASAE, St. Joseph, MI 49085.

2 Allen, R. R. and J. T. Musick. 1972. Wheat and grain sorghum irrigation in a wide bed-furrow system. TRANSACTIONS of the ASAE 15(1):61-63.

3 Allen, R. R., J. T. Musick and A. F. Wiese. 1975. No-till management of furrow irrigated continuous grain sorghum. Texas Agr. Expt. Sta. Prog. Rept. PR-3332 C.

4 Allen, R. R., J. T. Musick, F. O. Wood and D. A. Dusek. 1969. Grain sorghum yield responses to seeding date, days to maturity, and irrigation level in the Texas Panhandle. Texas Agr. Expt. Sta. Prog. Rept. PR-2697.

5 Jones, D. P. 1974. Energy considerations in crop protection. Outlook on Agr. 8(3):141-147.

6 Miles, J. A. 1975. Energy savings through alternative fuel utilization in desert agriculture. ASAE Paper No. 75-1004, ASAE, St. Joseph, MI 49085.

7 Taylor, H. M., C. E. Van Doren, C. L. Godfrey and J. R. Coover. 1963. Soils of the Southwestern Great Plains Field Station. Texas Agr. Expt. Sta. Misc. Publ. 669.